AD-A016 451

PREDICTING THE RECTAL TEMPERATURE RESPONSE TO HEAT STRESS

Garold K. Osborn, et al

Naval Medical Field Research Laboratory
Camp Lejeune, North Carolina

October 1975

30804

U.S. NAVAL MEDICAL FIELD
RESEARCH LABORATORY
CAMP LEJEUNE, NORTH CAROLINA

Vol. XXV, No. 11 October 1975

PREDICTING THE RECTAL TEMPERATURE RESPONSE TO HEAT STRESS

by

Garold K. Osborn and Harold W. Carroli

Naval Medical Research and Development Command, Navy Department
Work Unit MF51.524.023-1011.1

DOCUMENT CONTROL DATA - R & D

Naval Medical Field Research Laboratory
Camp Lejeune, North Carolina 28542

Unclassified

PREDICTING THE RECTAL TEMPERATURE RESPONSE TO HEAT STRESS

Interim report

Garold K. Osborn
Harold W. Carroll, Ph.D.

Report date	Total no. of pages	No. of refs
October 1975	~~18~~ 19	12

Project No. MF51.524

Task No. MF51.524.023

Work Unit No. MF51.524.023-1011

Originator's report number(s): MF51.524.023-1011.1

Other report no(s) (Any other numbers that may be assigned this report): Vol. 25, No. 11

Approved for public release: distribution unlimited

Sponsoring military activity:
Naval Medical Research & Development Command
Navy Department
NNMC, Bethesda, Md. 20014

The accuracy of Givoni-Goldman's equations and of the power function equation, $Y = aX^b$ for the prediction of rectal temperature was determined for a sample of Marine troops undergoing different levels of heat strain. The equations of Givoni-Goldman, developed to be applied to heat-acclimatized men, were more accurate in their prediction when the observed values of rectal temperature were above rather than below 38.5°C. The effect of heat conditioning was to increase the difference between predicted and observed values so that the latter tended to be overestimated. When the rectal temperature-time response curve was projected, by means of the power function equation, to later time points from values measured at three time points early in the exposure, the projected values tended to be lower than observed values for subjects experiencing higher degrees of heat strain. While more than 50% of the differences between observed and projected values were less than 0.5°C, yet such individual differences could be as large as 1°C. The magnitude of such differences could not be related to the early observed responses. Either of these methods for predicting rectal temperature response to heat stress should be applied with the realization that the variability in accuracy may be considerable and should therefore be applied with caution in estimating the tolerance of men to any particular set of heat stress conditions. (U)

DD FORM 1473 (PAGE 1)
S/N 0102-014-6700

UNCLASSIFIED
Security Classification

D-23822

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Heat stress						
Heat conditioning						
Equations, Givoni-Goldman						
Equation, power function						
Rectal temperature prediction						

DD FORM 1 NOV 65 1473 ~~(BACK)~~

S/N 0102-014-6800

ia

UNCLASSIFIED

Security Classification

A-31409

Vol. XXV, No 11 October 1975

PREDICTING THE RECTAL TEMPERATURE RESPONSE TO HEAT STRESS

by

Garold K. Osborn and Harold W. Carroll

Physiology Division
NAVAL MEDICAL FIELD RESEARCH LABORATORY
CAMP LEJEUNE, NORTH CAROLINA 28542

Naval Medical Research and Development Command, Navy Department
Work Unit MF51 524.023-1011.1

Submitted by:

H. W. CARROLL, Ph.D.
Chief
Physiology Division

Approved by:

E. J. CLARKE, JR.
CAPT MC USN
Commanding Officer

SUMMARY PAGE

THE PROBLEM

1. To evaluate the accuracy of Givoni–Goldman's formulas for the prediction of rectal temperature response of heat-acclimatized men to heat stress when applied to a sample of Marine troops undergoing different levels of heat strain.

2. To evaluate the accuracy of rectal temperature values projected from early observed values by use of the power function equation, $y = ax^b$

FINDINGS

1. Closest agreement between observed values and those predicted by Givoni–Goldman's formulas was obtained when the heat strain, at comparable times of exposure, was highest. Conditioning the men in heat had the effect of lowering observed values of rectal temperature below predicted values.

2. Values of rectal temperature mathematically projected from early observed values tended to be lower than observed values when the heat strain was relatively high, and higher than observed values when the heat strain was mild.

RECOMMENDATIONS

1. Givoni–Goldman's formulas should perhaps be evaluated in a greater variety of conditions before being used to determine how long a period of time, on the basis of the predicted rectal temperature, any particular set of heat stress conditions can be safely tolerated. The formulas should be used only where conditions prerequisite to their application are fulfilled, i.e., all subjects are young, healthy, physically trained, and fully heat acclimatized. It is not recommended that any specific studies be devoted to further evaluation of the formulas' accuracy.

2. Because of the variability in individual response, mathematical projection from a few early observed values should not be used to predict a subject's rectal temperature at later times of the exposure. For this same reason, no research into the feasibility of using such means for the prediction of heat stress responses is recommended.

ADMINISTRATIVE INFORMATION

This study was supported by the Naval Medical Research and Development Command, Navy Department, under Work Unit MF51 524.023-1011, report 1. Interim report. Approved for publication 15 September 1975.

The authors acknowledge the technical assistance of Mr. H.J. Burns, Mr. J. Hamby, and Mr R Jackson.

Published by the Naval Medical Field Research Laboratory, Camp Lejeune, N.C. 28542

ABSTRACT

Forty young male Marines in a "short" exposure to work in heat, before and after a regime of conditioning in a hot or thermoneutral environment, underwent sufficient stress to raise their mean rectal temperature to a level of 38.3°C or higher. Their mean rectal temperature at the end of the 100 minute walk in the heat was, contrary to expectations, overestimated after but not before conditioning by Givoni Goldman's equations for the prediction of rectal temperature of heat-acclimatized men. Closer agreement between observed and predicted values was apparent when the subjects showed the higher degree of heat strain, i.e., before any conditioning treatment or in those conditioned in the thermoneutral rather than in the hot climate.

Thirty young Marines who, without any conditioning, experienced the least degree of heat strain in a four-hour exposure to work in the heat had a final mean rectal temperature (38.1°C) that was overestimated the most (by a mean value of 0.7°C) by the predictive equations.

The majority of the differences between observed and predicted values, when the actual mean rectal temperature was greater than 38.5°C, was less than 0.5°C. When the rectal temperature was less than 38.5°C after an hour of working in the heat, the majority of such differences was greater than 0.5°C. Thus, if an accuracy of less than 0.5°C is desirable, the predictive equations should be applied to men who will experience a relatively high degree of heat strain, whether they are acclimatized or not. Even so, the degree of variation is likely to be considerable with poor correlation between observed and predicted values for individual subjects.

Rectal temperature values of these subjects observed at 15, 20 and 25 minutes of the same work-in-heat exposures were used to determine, by a least squares fit, the values of intercept (a) and slope (b) for the power function equation, $y = ax^b$. With substitution of such intercept and slope values in the equation, rectal temperature values of individual subjects at later time points of the exposure were calculated.

Comparison of the calculated and observed rectal temperatures for time points of 100 minutes to 230 minutes showed that, while the mean value of differences was small and more than 50% of differences were less than 0.5°C, individual values of such differences could be as large as 1°C. The calculated values tended to be lower than observed values when the subjects experienced a relatively high degree of heat strain, as in the "short" exposure before conditioning. For individual forecasting of rectal temperature response, this method thus had an accuracy that some might consider unacceptable, especially since the magnitude of individual differences between observed and predicted values could not be related to the early observed responses.

SECTION I

APPLICATION OF GIVONI GOLDMAN'S EQUATION TO THE PREDICTION OF RECTAL TEMPERATURE IN HEAT-STRESSED MALE MARINES

INTRODUCTION

Predicting the tolerance of men to heat has involved many studies. A criterion often used to judge whether conditions are tolerable is the level of rectal temperature.[1-3] The ability to predict the level of rectal temperature of a group of men having certain characteristics at any given time of a heat exposure by means of formulas would be very useful in making decisions regarding the tolerability of some given set of heat stress conditions. This would be especially so if the values of the various factors used in the formulas could be readily determined. Such formulas for the prediction of rectal temperature responses of young, fit, heat-acclimatized men to variations in work, clothing, and climate were recently published.[4]

The formulas (equations) for the prediction of rectal temperature (Tre) have thus far been evaluated only by those who developed them. Heat stress experiments in our laboratory with male Marines provided the opportunity to further evaluate the equations. Since physiological responses in our men were recorded both before and after a program of conditioning, we considered it of interest to apply the equations to the responses of both acclimatized and unacclimatized men.

Our purpose in determining, in a limited way, some idea of the accuracy of the prediction equations may be regarded as a random application of the formulas. In addition, our experimental data provided an opportunity to assess the formulas' accuracy relative to the heat strain experienced by the subjects. It has not been our intent to analyze for sources of prediction error. In view of the many factors that enter into the formulas, such an analysis would encompass a much more comprehensive investigation than is represented by our experiments. The results of our application have been analyzed in terms of differences between observed and predicted values.

METHODS

Young male Marine volunteers were the subjects of these experiments. Their physical characteristics as well as some of their observed responses, such as body weight loss, water intake, and oxygen intake during work in the heat, are presented in Table 1. Maximum oxygen intake, determined according to the procedure of Mitchell *et al.*,[5] and height of the subjects were measured only once, at the time of the first assessment exposure.

In a "short" exposure experiment, conducted in March, the subjects were assessed in a 110-minute exposure to heat. They rested for 10 minutes in the heat chamber before beginning the 100-minute walk on the treadmill, dressed in shorts and boots. Cool water, in plastic pint containers, was provided for each subject. The water warmed to various degrees toward the temperature of the environment and was replenished as it was consumed *ad lib.* Table 1 shows that the amounts of water consumed were quite variable, either *per se* or in relation to the amount of water (body weight) lost. The assessment exposures of this experiment immediately preceded and followed 14 consecutive days of one-hour periods of bench-stepping, either in a hot (98°F, 67% RH) or in a "cool" (70°F, 50% RH) climate.

TABLE 1

Characteristics of Subjects and Some Responses During Heat Exposure

	Short Exposure												Long Exposure		
	Conditioned in Heat						Conditioned in Cool								
	Before			After			Before			After					
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Age (yr)	16	21.9	2.6				19	20.2	1.3				30	20.7	2.6
Body wt (kg)*	20	73.88	8.80	16	75.09	7.85	20	74.31	10.70	19	74.80	10.47	30	72.94	7.28
Body ht (cm)*	20	174.7	6.6				20	176.7	6.0				30	174.3	5.6
Body SA (m^2)*	20	1.894	0.1453	16	1.913	0.1353	20	1.914	0.1661	19	1.919	0.1635	30	1.878	0.1070
Max $\dot{V}_{O_2}$ (liter/min)	20	3.890	0.5470				20	3.808	0.4077				26	3.768	0.4445
$\frac{\text{Max } \dot{V}_{O_2}}{\text{Body wt}} \left(\frac{\text{ml/min}}{\text{kg}}\right)$	20	52.6	5.20				20	51.5	4.55				26	52.6	5.07
	During Assessment Exposure														
Body wt loss $\left(\frac{g/m^2}{hr}\right)^{\dagger}$	20	489.0	125.67	16	592.7	101.51	20	463.2	94.83	19	471.3	69.96	30	476.7	92.56
Water intake $\left(\frac{g/m^2}{hr}\right)^{\dagger}$	20	193.2	175.84	16	214.7	183.80	20	236.6	140.17	19	238.3	191.81	30	268.9	68.38
Water intake/body wt loss (%)	20	38.2	27.76	16	35.6	31.02	20	52.4	32.58	19	49.2	35.70	30	57.1	14.60
Submax $\dot{V}_{O_2}$ (liter/min)	20	1.475	0.1697	16	1.465	0.1813	20	1.413	0.1884	19	1.443	0.1472	30	1.151	0.1557
Submax $\dot{V}_{O_2}$/max $\dot{V}_{O_2}$ (%)	20	38.4	4.14	16	37.4	5.16	20	37.4	4.33	19	38.0	3.66	26	30.9	4.81

*Measured at beginning of assessment exposure. Surface area was calculated from values of body weight and height according to the formula of Dubois and DuBois.[10]

†Initial rest is included for the short exposure and excluded for the long exposure in the time basis of the calculated values. Water was measured as milliliters and assumed to weigh 1 gm/ml.

During conditioning in the heat, the men worked at rates (12 and 24 steps per minute) sufficient to raise and maintain their rectal temperatures at a minimum level of 38.3°C. As conditioning progressed, more time at the faster stepping rate was required to reach this temperature level so that more work was performed during the latter than during the initial days of conditioning. Those subjects conditioned in the cool environment worked for a time at the two stepping rates equivalent to the average work time of the heat-conditioned group on the same day, so that by the end of the conditioning period there was no difference in the mean work outputs of the two groups.

In a "long" exposure experiment, which extended from April through August, each subject worked in a single exposure to heat without any conditioning treatment. The exposure consisted of an initial rest period of 45 minutes in the heat chamber, followed by an attempt to walk for four 50-minute periods, separated by 10-minute intervals of rest in the heat. If a subject attained a rectal temperature of 39.2°C or a heart rate of 180 beats per minute or showed symptoms of heat distress, such as dizziness, headache, syncope, the exposure was discontinued. The men were clothed in denim uniforms and boots. While walking on the treadmill, they wore a helmet and carried a 50-pound backpack. Drinking water, of cool to warm temperature, was supplied at the rate of 800 cc per hour.

Values of climatic factors and mean values of the other factors required for the solution of Givoni and Goldman's predictive equations are presented in Table 2 for the short- and long-exposure experiments.

A setting of two permanent fans in the heat chamber provided the desired air movement, the velocity of which was measured by an anemometer placed in front of the treadmill. Temperature of the heat chamber was continuously monitored to maintain nearly constant dry- and wet-bulb conditions.

In the short-exposure experiment, dry- and wet-bulb temperatures were recorded at frequent intervals by the same electronic system that recorded rectal temperature. Median values of dry-bulb and wet-bulb temperatures determined for each subject were used in

TABLE 2

Mean Values of Factors of the "Short" and "Long" Exposure Experiments for the Prediction of Rectal Temperature

	"Short" Exposure				"Long" Exposure
	Before Conditioning		After Conditioning		
	In Heat	In Cool	In Heat	In Cool	
Total mass (kg)	76.121	76.614	77.374	77.079	95.636
DBT (°C)	37.19	37.02	37.02	37.03	32.28
WBT (°C)	30.60	30.59	30.59	30.60	28.88
RH (%)	62.1	62.9	62.9	62.9	77.6
BP (mmHg)	765.14	765.14	763.56	763.02	762.0
VP (H_2O) at WBT (mmHg)	32.94	32.92	32.91	32.94	29.835
Walking speed (m/sec)	1.564				1.341
Walking grade (%)	3				0
Air speed (m/sec)	1.016				1.028
Exponent for clo and im/clo	±0.3				±0.25
Factor for clo	0.57				0.99
Factor for im/clo	1.2				0.75

the equations for predicting his rectal temperature. Median values of wet-bulb temperatures were used to calculate the water-vapor pressure during exposure. Median water-vapor pressure, dry-bulb temperature, wet-bulb temperature, and a mean barometric pressure were used to calculate the vapor pressure of the chamber environment.

In the long-exposure experiment, the dry-bulb temperature, wet-bulb temperature (recorded once per hour), and an arbitrarily selected barometric pressure were used to calculate the vapor pressure of the chamber environment.

Insulation and permeability factors, for the type of dress, were taken from Givoni and Goldman's Table 1.[2] Their equations were used to calculate total and net metabolic heat production rates for each subject.

Predicted rectal temperature at various time points during work was calculated for each subject. The predictive equations of Givoni and Goldman are presented in Appendix A. In the calculation of the initial Tre at work, the duration of the initial rest period was combined with the calculated time delay for Tre to be affected by work. The difference between this procedure and that of independent consideration of the two time periods appears to have negligible effect on the predicted rectal temperature at the start of or during the work period. The expression for the time constant (k) given in the footnote on page 815[2] was employed in the use of the equation for calculations of rectal temperature during work. Variable N in tabulating the results may be due to (a) deliberate exclusion of a value considered as erroneous, (b) an unrecorded datum, or (c) cessation of a subject's performance.

Rectal temperature was recorded by means of a digital electronic device connected to a thermistor with the latter instrument inserted in the rectum to a depth of 10 cm from the external sphincter. Oxygen consumption rates were determined with the use of a Beckman paramagnetic analyzer (E 2) and a spirometer. These rates were determined from three-minute expired air samples collected at 50 minutes of work in the short-exposure experiment and at 20 minutes of each hour of work in the long-exposure experiment.

In the tabulation of results, the initial rest periods are not included in the specification of exposure times. In the long-exposure experiment such specified times, following time 0 minutes, are those at the end of 50-minute work periods.

RESULTS

Table 3 (column 5) shows that mean values of observed Tre at the end of an exposure were highest in the short-exposure experiment, before conditioning, and lowest in the long-exposure experiment. These values were such that the men stressed in early spring (short-exposure experiment) could be considered to have experienced a relatively "high" degree of heat strain before conditioning and a more moderate degree of strain after conditioning, whereas those subjects stressed in spring and summer months (long-exposure experiment), without any conditioning treatment, experienced a "mild" degree of strain.

Our application of Givoni–Goldman's equations indicated a definite tendency for the equations to overestimate the values of observed Tre. This is shown in Table 3 (column 9) by the negative sign of the mean value of the observed minus predicted Tre values at all three levels of heat strain experienced by the subjects, i.e., before and after conditioning in

the short-exposure experiment and at the end of each work period in the long-exposure experiment. It was also demonstrated (not presented in a table) by the much greater frequency (60% or more) of negative differences for observed minus predicted Tre values in the short-exposure experiment and by the observation that all such differences were negative following the first work period in the long-exposure experiment.

The difference between observed and predicted values at the end of work periods in the heat was least in subjects experiencing a high degree of heat strain and greatest in those experiencing a mild degree of strain. Thus, in the short-exposure experiment, the mean of such differences before conditioning was small and nonsignificant. It was practically zero in that group of subjects, conditioned later in the cool environment, having the higher mean value of observed Tre (Table 3, columns 9, 12, and 5). Both the mean of differences and the mean of the observed final Tre of the heat-conditioned group were significantly different

TABLE 3

Data with Respect to Observed and Predicted Rectal Temperatures (°C) During Work in the Heat

1	2	3	4	5	6	7	8	9	10	11	12	13	14
					Variance		Variance Diff*	Mean Diff**				Obs vs Pred	
Conditioning	Group	Time (min)	N	Mean Obs*	Obs	Pred*	F†	Diff	SD*	CV*	P†	rho*	P††
							(Short) Exposure Experiment						
Before	Heat	0	20	37.06	0.1437	0.0147	<0.001	-0.06	0.38	634.7	>0.10		
	Cool	0	20	37.19	0.1576	0.0222	<0.001	+0.06	0.32	506.5	0.10		
	Heat	100	19	38.79	0.1389	0.0566	>0.05	-0.16	0.33	214.5	>0.05	+0.400	<0.05
	Cool	100	18	38.65	0.1104	0.0627	>0.10	-0.04	0.35	829.5	>0.10	+0.174	>0.10
After	Heat	0	16	36.83	0.0997	0.0118	<0.001	-0.31	0.33	106.1	<0.01		
	Cool	0	19	37.08	0.1160	0.0211	<0.001	0.06	0.29	504.5	>0.10		
	Heat	100	16	38.32	0.0326	0.0358	>0.10	-0.64	0.22	34.4	<0.001	+0.260	>0.10
	Cool	100	18	38.65	0.1109	0.0627	>0.10	-0.30	0.38	124.5	<0.01	+0.120	>0.10
							(Long) Exposure Experiment						
		0	29	37.15	0.0677	0.0069	<0.001	+0.02	0.26	15.7	>0.10		
		50	30	37.87	0.0856	0.0150	<0.001	-0.41	0.26	64.5	<0.001	+0.454	<0.005
		110	27	37.95	0.1681	0.0128	<0.001	-0.70	0.36	51.3	<0.001	+0.971	<0.005
		170	25	38.01	0.1532	0.0107	<0.001	-0.75	0.35	47.1	<0.001	+0.497	<0.01
		230	21	38.08	0.1728	0.0112	<0.001	-0.72	0.37	51.8	<0.001	-0.550	<0.005

*Obs = observed; Pred = predicted; Diff = difference; SD = standard deviation; CV = coefficient of variation = SD/mean; rho = Spearman rank correlation coefficient, ref. 11, pp. 202-213.

†P = probability for 2 tail Student's t test. Where P of variance difference <0.05, P value of mean difference (column 12) is that corresponding to 0.5 x normal degrees of freedom, ref. 6, p. 185; t for correlated variances = $(var_1 - var_2)\sqrt{N-2} / \sqrt{4\, var_1\, var_2 (1 - r^2)}$ from ref. 12, p. 282 (column 8).

**Mean difference = observed mean minus predicted mean.

††P for Spearman rank correlation is for 1 tail test.

from such means of the cool-conditioned group only after conditioning. Significance at P level of 0.01 was determined by "t" test with formulas appropriate for equal and unequal variances.[6]

More than 75% ($P < 0.01$)* of differences between observed and predicted temperatures at end of the exposure were less than 0.5°C before conditioning treatment. After conditioning, the mean of such differences became much greater and significant, with a larger mean value observed in the group (conditioned in the heat) having the lower mean value of observed Tre (Table 3, columns 5 and 9). In this latter group, only a small and significant* percentage (25%) of the differences after conditioning between observed and predicted Tre values was less than 0.5°C. In the long-exposure experiment, the mean of differences was greater than 0.5°C (Table 3, column 9) and the percentage of differences (30% or less) $\lessapprox$ 0.5°C was significantly small after the first work period.

The magnitude and sign of differences between observed and predicted values of Tre were quite variable. The magnitude of variation is illustrated by the large size of the coefficient of variation in Table 3 (column 11), especially when the mean value of differences was least (column 9). Table 4 shows that maximum differences could be 1°C or larger (e.g., in the long-exposure experiment where the mean of differences was also large) or that a positive difference could be as large as a negative difference (e.g., in the heat-conditioned group before conditioning where the mean of differences was small). The presence of low and nonsignificant values of the rank correlation coefficient (Table 3, columns 13 and 14) also illustrate indirectly the quite variable nature of the differences between observed and predicted values.

DISCUSSION

The results of our application of Givoni–Goldman's equations showed a greater accuracy for subjects experiencing a relatively high degree of strain. The results were contrary to those expected since the equations, developed to be applied to heat-acclimatized men, yielded closer approximations of observed values of Tre before than after heat acclimatization. In subjects experiencing lower levels of heat strain, as in those after heat conditioning in the short-exposure experiment and in those of the long-exposure experiment who had probably acquired a certain degree of "natural" acclimatization, the rectal temperature tended to be consistently overestimated. While dependence on this characteristic of the predictive equations should have the effect of protecting subjects from the risk of developing excessive body temperature, the magnitude of the overprediction could make such dependence wasteful in a decision of whether or not to expose acclimatized subjects to a certain degree of heat stress.

While our results represented a limited application of the predictive equations, they illustrate the large variation in accuracy that is possible in a random application. That the body temperature of acclimatized men could be overpredicted by more than 0.5°C in a majority of the subjects might be considered by some to be beyond the accuracy required in a practical application.

---

*P value was determined by the binomial distribution on the basis that the expected frequency of such differences equal to or less than 0.5°C equals 50%

TABLE 4

Maximum Positive and Negative Differences Between Observed minus Predicted Rectal Temperatures (^{o}C)

Time (min)	Short Exposure Experiment												Long Exposure Experiment		
	Conditioned in Heat						Conditioned in Cool								
	Before Acclim			After Acclim			Before Acclim			After Acclim					
	N	+Diff	−Diff	N	+Diff	−Diff	N	+Diff	−Diff	N	+Diff	−Diff	N	+Diff	−Diff
0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	19	[illegible]	[illegible]			
60													30	[illegible]	1 10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	none	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 06	[illegible]	none	[illegible]
[illegible]													[illegible]	none	[illegible]
[illegible]													21	none	[illegible]

The more or less consistent overestimation of the values by the predictive equations suggests that better accuracy might be obtained by an adjustment of the equations. Because of so many factors in the equations, and consequently a large number of possible adjustments, the task of trying to significantly improve the accuracy might be considered, if not offering a small chance of success, uneconomical with respect to the effort involved. Since measurements were taken, however, of two factors which are estimated by the equations and which have relatively large effects on their results, we thought it would be of interest to use the observed rather than the estimated values of such factors to determine the effect of such substitution on the predictive accuracy. These measured factors were the rectal temperature at start of work and the rate of oxygen consumption converted into rate of heat production (on the basis of 5 kcal/liter of O_2 and 1 16278 watts/kcal/hr)

The mean value of differences between observed and predicted values of final Tre was reduced but remained significant ($P<0\ 01$) after substitution of observed values of either initial rectal temperature or metabolic rate. Mean values were reduced by $0.05^{o}C$ with substitution of rectal temperature values and by $0.02^{o}C$ with substitution of metabolic rates, but the variation of such differences was not reduced. A "t" test of differences with no substitution versus differences with substitution showed that a significant reduction in differences was obtained with substitution of observed values of initial Tre ($P<0\ 025$) but not with those of metabolic rate ($P>0\ 10$) This result reflected the fact that the difference between observed and predicted mean values of initial Tre was significant ($P<0.01$) but such difference in metabolic rate was nonsignificant ($P>0.10$). The presence of a significant difference ($P<0\ 01$) between observed and predicted final temperature values, even after simultaneous substitution of observed values of both factors, showed that additional factors operated in producing the original discrepancies. The fact that the difference between observed and predicted values of initial Tre was poorly and nonsignificantly correlated ($r = -0\ 05$, $P>0.05$) with such difference of final Tre in the same group of subjects after acclimatization also indicated that the estimation of initial Tre was not the only source of error in the prediction of final Tre. We conclude from this analysis that some improved accuracy of prediction may be obtained by an adjustment of Givoni–Goldman's formula for estimating the initial Tre value, and we concur with Givoni and Goldman that the prediction of this value needs more experimentation [4]

Presumably, observed responses could be overestimated by the prediction equations, as seen in our experiments, if applied to subjects who, by reason of being more highly trained, produced less of a heat load than did those used in the development of the equations. Men, when working in the heat, undergo less strain after than before a regime of training in a cooler climate during which their body temperature is kept elevated and as a consequence of which their oxygen requirement for the work task is reduced and their physical fitness (and presumably max $\dot{V}_{O_2}$) is improved.[7,8] It would seem doubtful that a difference in heat production for the work task employed in the present experiments between our subjects and those used by Givoni and Goldman would be great enough to account for the results that we obtained in application of the predictive equations. Our two groups of subjects in the short-exposure experiment after conditioning differed significantly ($P<0.005$) from each other with respect to the discrepancies between observed and predicted final temperatures without differing significantly in max $\dot{V}_{O_2}$ rates ($P>0.20$) and the oxygen consumption rates during the walk in the heat ($P>0.10$).

Part of the variation in differences between observed and predicted values of Tre during and at the end of a heat exposure could possibly be due to the variations in water intake and the degree of heat acclimatization, especially of those subjects assessed without any conditioning treatment during spring and summer months. In the absence of conditioning treatment and with water intake, on the average, insufficient to replace that lost, values of observed Tre were still lower than predicted values. If these factors had been important in influencing the differences between observed and predicted values of Tre, then one would expect that the observed values would have been underpredicted rather than overpredicted. It would seem unlikely that the overprediction would be due to "coolness" of the water consumed since it was drunk in relatively small quantities and over time periods when it warmed to various degrees toward the temperature of the body. Even if the variation in predictive accuracy could be reduced by more rigorous control of influential factors than was obtained in our experiments, the equations should still perhaps be applied with caution, especially in view of the many factors that can influence thermoregulation,[9] all of which are not included in the equations.

SECTION II

RECTAL TEMPERATURE PREDICTION BY MATHEMATICAL PROJECTION OF EARLY OBSERVED RESPONSES

The rectal temperature-time response curve for men exposed to heat stress, in showing a decreasing slope with time until a steady state is reached, describes a relationship that appears to fit the mathematical equation, $y = ax^b$ We thought it would be of interest to determine, in a random sample so to speak, how accurately rectal temperature response at various times of exposure might be predicted by projection of the curve from a few early observed responses. Such a response curve, determined for an individual, if reasonably accurate, could provide a means by which to estimate how long the conditions of exposure might be safely tolerated by the individual

The heat stress responses of young male Marines who participated in the experiments reported in Section I of this report were used to test the predictive accuracy of the power function equation. Values of rectal temperature (Tre) observed at 15, 20 and 25 minutes of a work-in-heat exposure were substituted in the equation for a least squares determination of intercept (a) and slope (b), then, with substitution of these latter values in the regression equation, the subject's predicted temperature at later time points of the exposure were calculated The differences between such predicted and observed responses in a "short" exposure (110 minutes) and a "long" exposure (230 minutes) were analyzed.

The analysis showed that while as many as 81% at the end of the "short" exposure and 70% at the end of the "long" exposure of the differences between observed and predicted Tre were $\leq$0.5°C, with mean values of differences of 0.3°C or less, some subjects had differences as large as 0.6 to 1°C Observed values of Tre were, on the average, greater than predicted values where the heat strain was relatively high (as indicated by a mean observed Tre value of 38.9°C at the end of the "short" exposure) and less than predicted values where the heat strain was mild (as indicated by a mean observed Tre value of 38.1°C at the end of the "long" exposure). Mean differences became greater with successive 50-minute work periods in the "long" exposure.

These results indicate the precariousness of utilizing this means of rectal temperature prediction for the purpose of estimating an individual's tolerance to heat stress, especially since the magnitude of differences between final values of observed and predicted Tre had no apparent relationship to the early observed rectal temperature responses and, hence, precluded the possibility of forecasting a large discrepancy in the predicted value of a given subject On the other hand, the results indicated the possibility of estimating the mean response of a group of subjects with what may be considered a reasonable degree of accuracy, especially when the means of prediction is applied to responses to moderate heat stress of less than four hours of duration.

REFERENCES

1. Eichna, L.W., W.F. Ashe, W.B. Bean, and W.B. Shelley. The upper limits of environmental heat and humidity tolerated by acclimatized men working in hot environments. *J. Indust. Hyg. Toxicol.* 27:59-84, 1945.

2. Lind, A.R. A physiological criterion for setting thermal limits for everyday work. *J. Appl. Physiol.* 18:51-56, 1963.

3. Wyndham, C.H., N.B. Strydom, J.F. Morrison, C.G. Williams, G.A.G. Bredell, J.S. Maritz, and A. Munro. Criteria for physiological limits for work in heat. *J. Appl. Physiol.* 20:37-45, 1965.

4. Givoni, B. and R.F. Goldman. Predicting rectal temperature response to work, environment, and clothing. *J. Appl. Physiol.* 32:812-822, 1972.

5. Mitchell, J.H., B.J. Sproule, and C.B. Chapman. The physiological meaning of the maximal oxygen intake test. *J. Clin. Invest.* 37:538-547, 1958.

6. Downie, N.M. and R.W. Heath. *Basic Statistical Methods.* Harper and Row, New York, 3d edition, 1970

7. Marcus, P. Heat acclimatization by exercise-induced elevation of body temperature. *J. Appl. Physiol.* 33:283-288, 1972.

8. Strydom, N.B., C.H. Wyndham, C.G. Williams, J.F. Morrison, G.A.G. Bredell, A.J.S. Benade and M. von Rahden. Acclimatization to humid heat and the role of physical conditioning. *J. Appl. Physiol.* 21:636-642, 1966

9. Belding, H.S. The search for a universal heat stress index. *In* Hardy, J.D., A.P. Gagge, and J.A.J. Stolwijk. *Physiological and Behavioral Temperature Regulation.* Charles C. Thomas, Springfield, Ill., 1970, p. 193.

10. DuBois, D. and E.F. DuBois. A formula to estimate the approximate surface area if height and weight be known. *Arch. Intern. Med.* 17:863-871, 1916.

11. Siegel, S. *Nonparametric Statistics for the Behavioral Sciences.* McGraw-Hill Book Co., Inc., New York, 1956.

12. McNemar, Q. *Psychological Statistics.* John Wiley and Sons, Inc., New York, 4th edition, 1969.

APPENDIX A

Givoni–Goldman's Equations for the Prediction of Rectal Temperature of Young, Physically Fit. Heat-Acclimatized Men in the Heat

(Note: In expressing the negative sign of an exponent, the sign is placed in parentheses preceding the abbreviation, exp. For instance, e (–) exp w = e^{-w}.)

1. Equilibrium Tre

Tre (equil) = 36.75 + 0.004 (Mr or Mnet) + (0.025/clo) (DBT – 36) + 0.8 e exp HE

Mr = 105, used to find equilibrium Tre at rest

Mnet = Mw – W, used to find equilibrium Tre at work

Mw = $m_t n$ [(2.7 + 3.2 (v – 0.7)$^{1.65}$) + G (0.23 + 0.29 (v – 0.7))]

w = 0.098 $m_t vG$

exp HE = 0.0047 (Er – Em)

Er = Mnet + SA/1.8 (11.6/clo) (DBT – 36)

Em = SA/1.8 (25.5) (im/clo) (44 – VPa)

clo (rest) = fa (Va) (–) exp a

clo (work) = fa [Va + 0.004 (Mw – Mr)] (–) exp a

im/clo (rest) = fb (Va) exp b

im/clo (work) = fb [Va + 0.004 (Mw – Mr)] exp b

VPa = VP – 0.00066BP (DBT – WBT) (1 + 0.00115 WBT) (from *Handbook of Chemistry and Physics*, 45th ed., p.E-27)

2. Tre at time t of rest

Tre_t (rest) = Tre_0 + (Tre (equil) – Tre_0) (0.1) exp 0.4 exp (tr – 0.5)

Tre_0 = 36 + 0.015 BW; for Tre (equil), use the value for rest

3. Tre at time t of work

Tre_t (work) = Tre_0 + (Tre (equil) – Tre_0) (1 – e (–) exp w)

Tre_0 = Rest or Recovery Tre_t for t = t_d; for Tre (equil), use the value for work

exp w = 2 (e (–) exp 0.17 (Tre (equil) – Tre_0) (tw – t_d))

t_d = 58/Mw

4. Tre at time t of recovery

Tre_t (rec) = Tre_0 – (Tre_0 – Tre (equil)) (1 – e (–) exp rec)

For Tre (equil), use the value for rest

Tre_0 = 0.5 (Tre_T (work) – Tre_t (work)) + Tre_t (work)

T = t (work) + t_d (rec)

t_d (rec) = 0.25 e (–) exp 0.5 CP_{eff}

$CP_{eff} = \left\{[0.27 \text{ (im/clo) } (44 - \text{VPa}) + (0.174/\text{clo}) (36 - \text{DBT})] - 1.57\right\} \frac{SA}{1.8}$

For CP_{eff}, use rest values of im/clo and clo

exp rec = a (t (rec) – t_d (rec))

a = 1.5 (1 – e (–) exp 1.5 CP_{eff})

5. Meaning of symbols

Tre = rectal temperature (^{o}C)
Mr = metabolic rate at rest (watts)
Mnet = net metabolic rate (watts)
clo = clothing insulation unit
DBT = dry bulb temperature (^{o}C)
Mw = metabolic rate at work (watts)
m_t = total weight (body and load) (kg)
n = terrain factor (= 1 for treadmill)
v = speed of walking (m/sec)
G = grade of walking (%)
W = energy expended as external work (watts)
Er = required evaporative cooling (watts/^{o}C)
Em = evaporative capacity of the environment (watts/mmHg)
SA = surface area of subject's body (m^2)
im/clo = clothing permeability unit
VPa = water vapor pressure of the air (mmHg)
fa and exp a = coefficient and exponent to obtain effective clo units appropriate to type of clothing (from Table 1, p 815 of reference 4)
fb and exp b = coefficient and exponent to obtain effective im/clo units appropriate to type of clothing (from Table 1, p. 815 of reference 4)
Va = speed of air movement (m/sec)
VP = water vapor pressure of air at wet bulb temperature (mmHg)
BP = barometric pressure (mmHg)
WBT = wet bulb temperature (^{o}C)
t = time duration (hours); tr = time duration at rest; tw = time duration of work; trec = time duration of recovery (resting) in the heat following a period of work
Tre_0 = initial rectal temp. (^{o}C); for rest, Tre_0 is the value upon introduction to heat; for work, Tre_0 is the rest value of Tre_t at the end of the delay period, t_d; for recovery, Tre_0 is 0.5 x the work value of Tre_t at the end of the delay period, t_d (rec)
BW = body weight (kg)
t_d = time delay before Tre is affected by work (hours)
t_d (rec) = time delay before Tre is affected by rest following work (hours)
CP_{eff} = effective cooling power (watts)